Space Solar Power Concept & Technology Maturation (SCTM)
Program Technical Interchange Meeting
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Ohio Aerospace Institute

Nanomaterials for Space Solar Power

NASA-NSF-EPRI Joint Investigation of Enabling Technologies for SSP (JIETSSP)

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Introduction

• Photovoltaic conversion with conjugate polymers.
G. Yu, J. Gao, J. Hummelen, F. Wudl, and A.J. Heeger, *Science* **270**, 1789 (1995).

• Exciton dissociation can be enhanced via electron accepting impurities. M. Granstrom, K. Petrisch, A.C. Arias, A. Lux, M.R. Andersson, and R.H. Friend, *Nature* (London) **395**, 257 (1998).

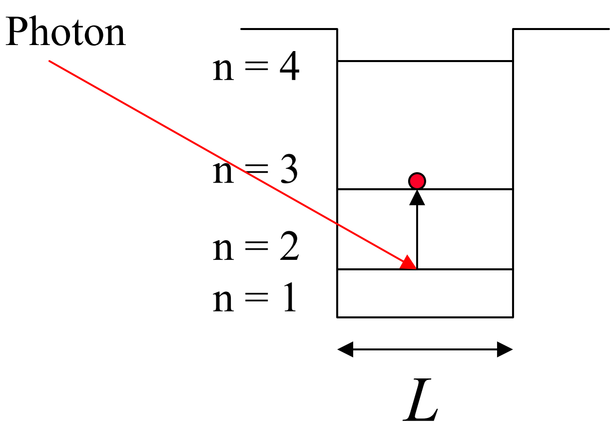
• A variety of acceptor materials are under investigation (e.g., buckminster fullerenes, CdSe quantum dots and nanorods, single wall carbon nanotubes). E. Kymakis and G.A.J. Amaratunga, *Appl. Phys. Lett.* **80**, 1 (2002), C.W. Tang, *Appl. Phys. Lett.* **48**, 183 (1996), V. Aroutiounian, S. Petrosyan, A. Khachatryan, K. Touryan, *J. Appl. Phys.* **89**, 4 (2001).

• Theoretical studies predict a potential efficiency of 63.2% for a single size quantum dot in a p-i-n type cell structure (86.5 % for a graded dot structure). A. Luque and A. Marti, *Phys. Rev. Lett.* **78**, 5014 (1997).

Quantum Dots

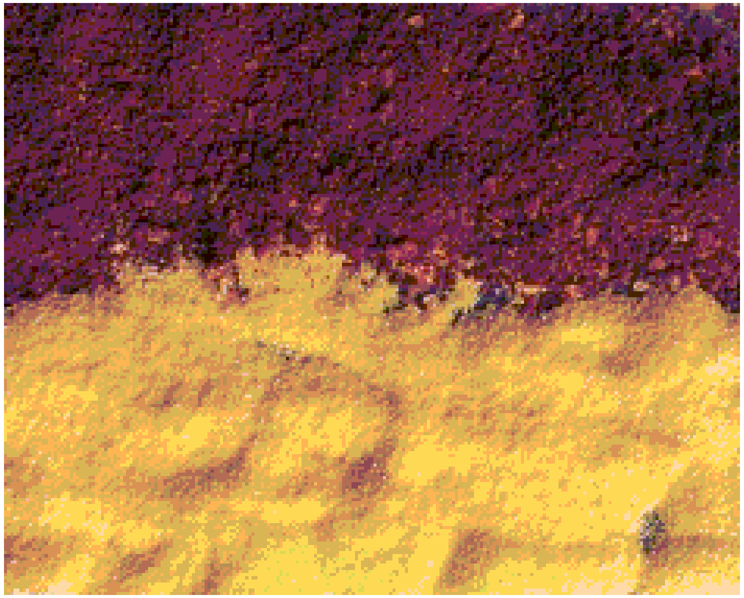
Quantum dots are granules of a semiconductor material whose size is on the nanometer scale. These nanocrystallites behave essential a potential well for electrons trapped within it (i.e., the quantum mechanical “particle in a box”).

$$E_n = \left(\frac{h^2}{8mL^2}\right)n^2$$



$$\lambda_t = \frac{hc}{E_t}$$

The size of the particle will dictate the threshold energy that it may absorb.



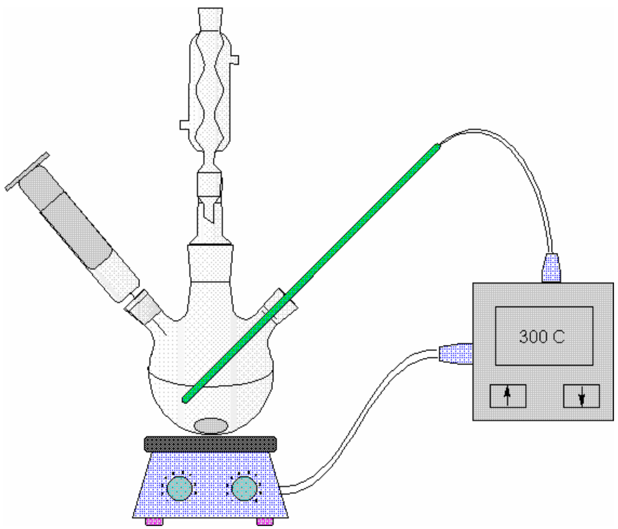
Two samples of the semiconductor cadmium selenide, the only difference being the size of the crystallites.

Current Quantum Dot Usage

- Color Tags for Biomolecules
- Quantum-dot Lasers
- Light-emitting Diodes
- Photodetectors

Nanomaterials Synthesis – Quantum Dots

Organometallic Synthesis

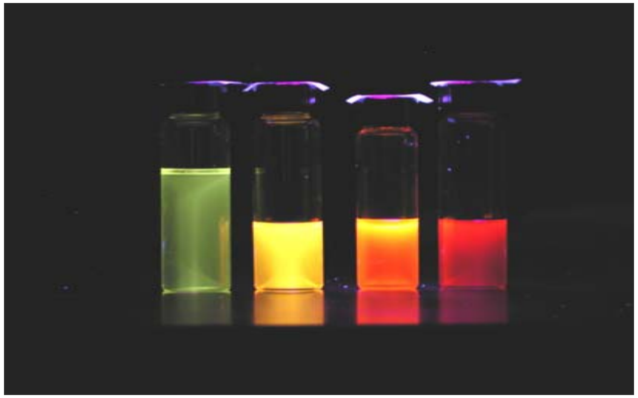


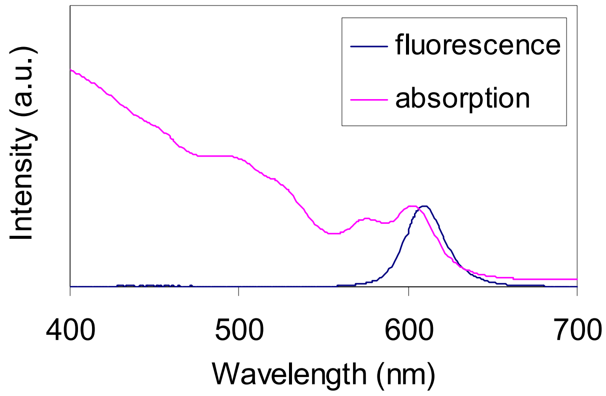
Trioctylphosphine oxide (TOPO) is heated under an inert atmosphere to between 300 and 350 C.

- Dimethylcadmium (Me2Cd) and trioctylphosphineselenide (TOPSe) is diluted in trioctylphosphine (TOP)

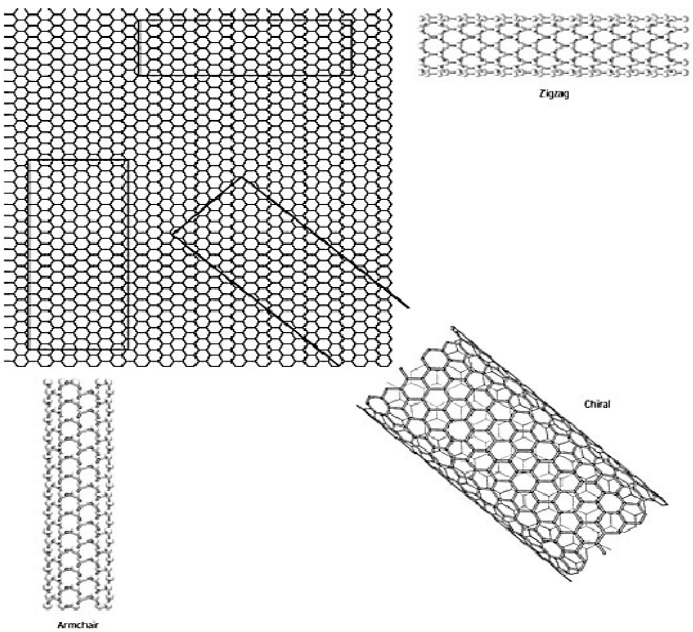
- The contents of the syringe are injected into the hot TOPO with vigorous stirring.
When the desired size is reached, the heat is removed from the flask.

- Upon cooling, methanol is added to remove excess reagents and solvents, yielding a powder of TOPO-capped CdSe nanocrystals.

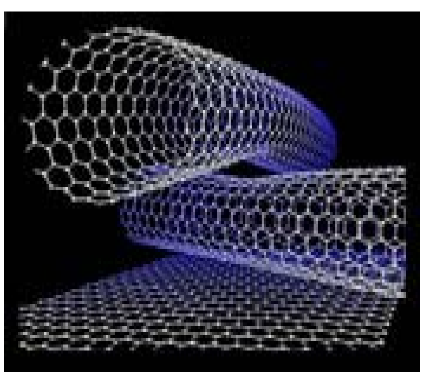


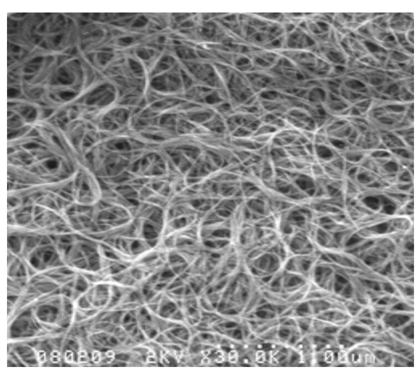


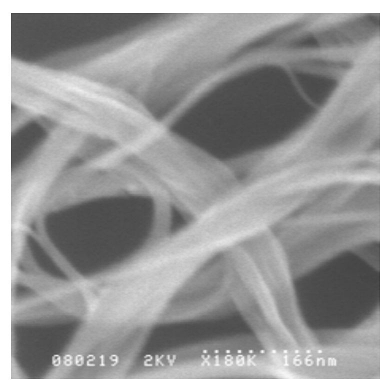
Single Wall Carbon Nanotubes

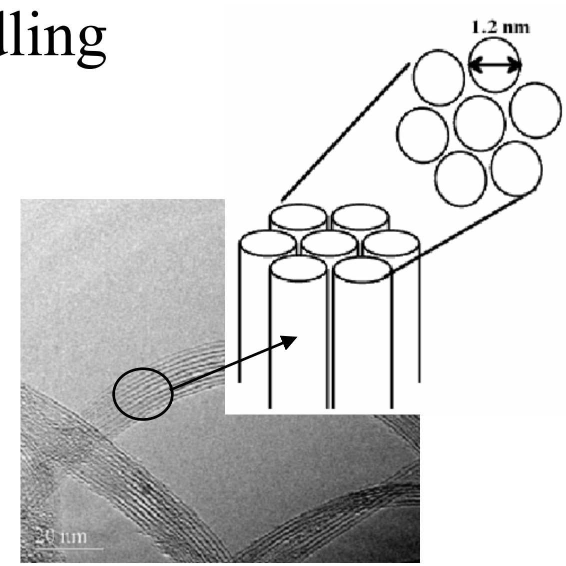


- Organized nanostructured carbon
- Diameters: 0.4 to 2.0 nm
- Lengths: 0.01 to 100 μm
- Metallic or Semiconducting
- High electrical and thermal conductivity
- Flexible
- High tensile strength (i.e., ~ 20 Gpa)
- Van Der Waal Bundling
- Functionalization



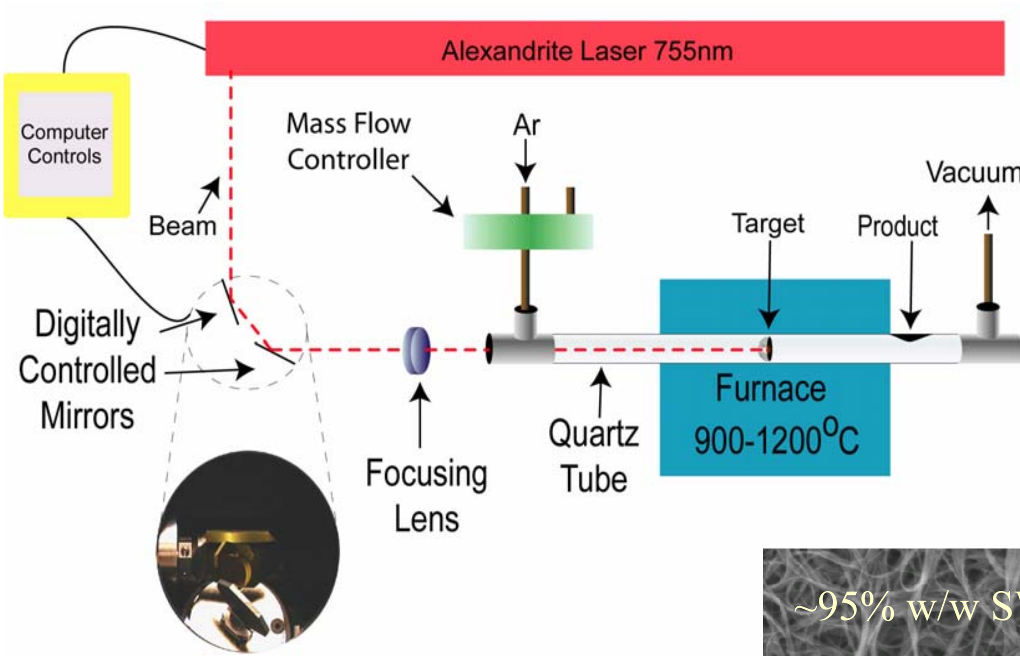


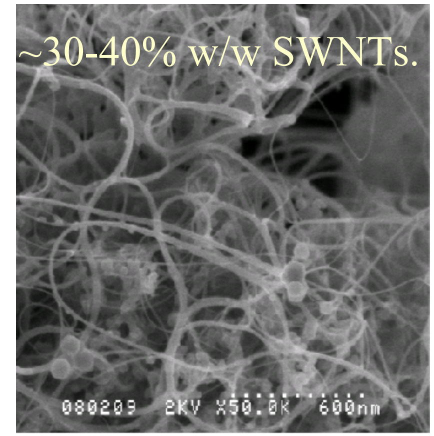




Nanomaterial Synthesis - SWCNT

Laser Vaporization Synthesis

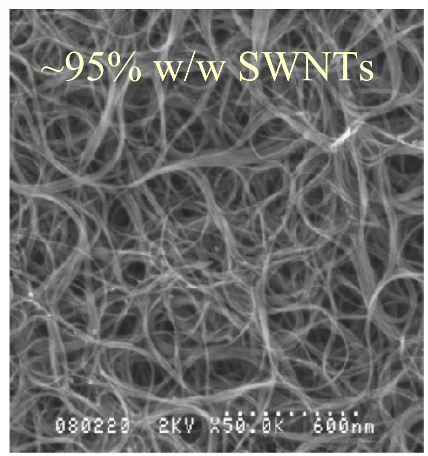




"raw soot"

Typical Conditions

- Ni/Co (0.6 at. % each) graphite target
- 1200 °C furnace temperature
- 50-150 W/cm^2 power density
- 100 sccm $Ar_{(g)}$



"purified"

- Nitric acid reflux for 16 hours at 125 ºC.
- Filtered using 0.2 µm Anodisc, and dried 1 hr at 70 ºC *in vacuo*.
- Thermal oxidation at 500 ºC.
- Anneal at 1200 ºC under $Ar_{(g)}$, if necessary.

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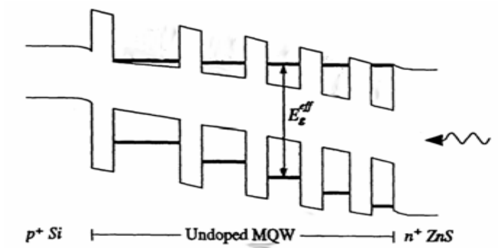
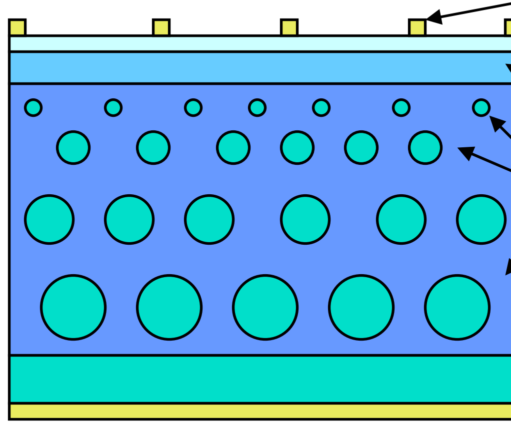
Quantum Dot Solar Cells

Quantum Dot Solar Cell Schematic

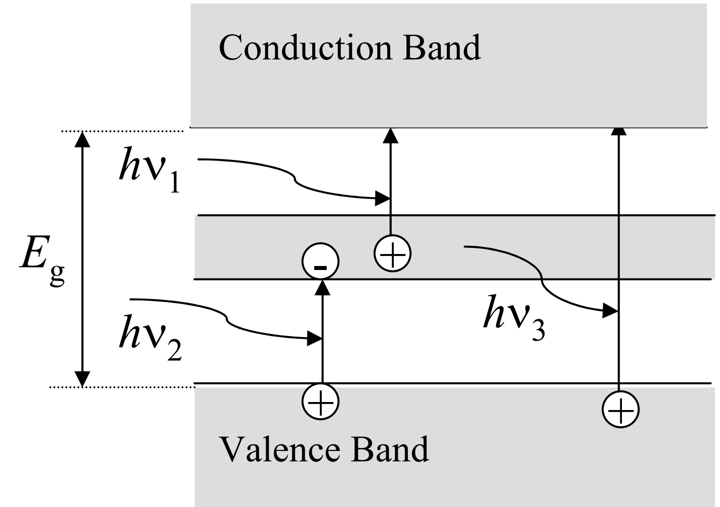
The quantum dots are sandwiched in an intrinsic region between the ordinary *p* and *n* type regions of a photovoltaic solar cell.



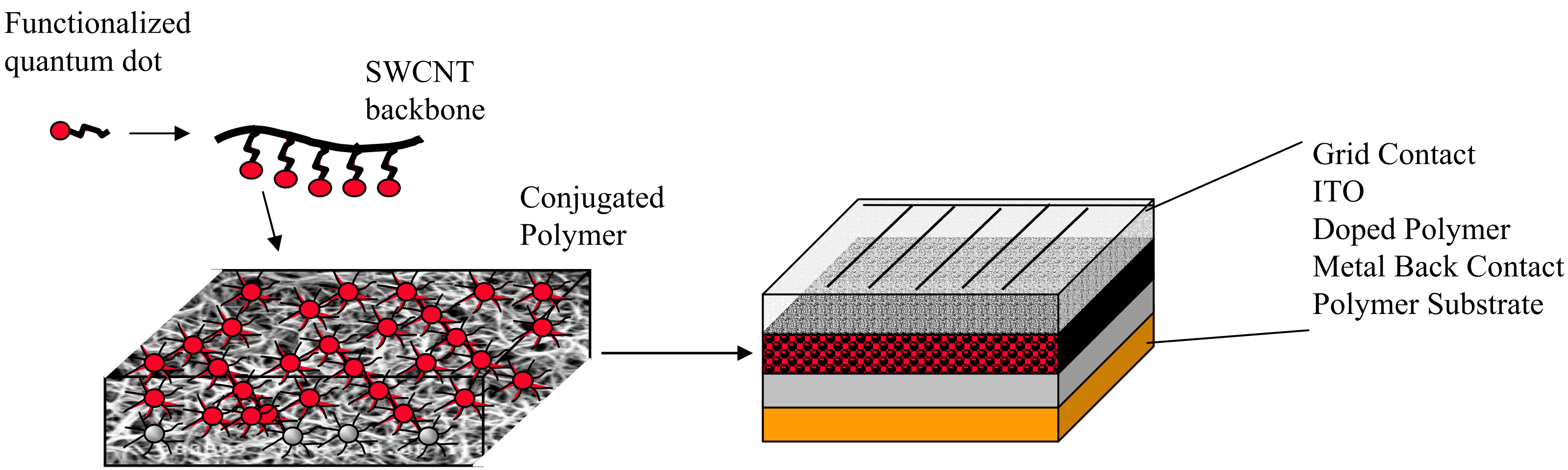


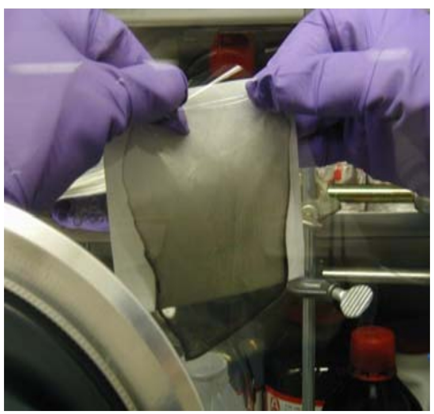
Operational Principle

The quantum dots form an intermediate band of discrete states that allow for the absorption of sub-bandgap energies. However, when the current it extracted it is limited by the bandgap and not the individual photon energies.

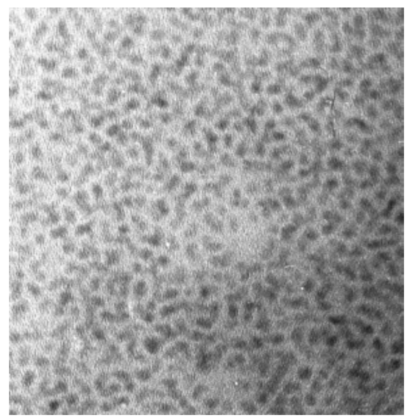


Basic Cell Design

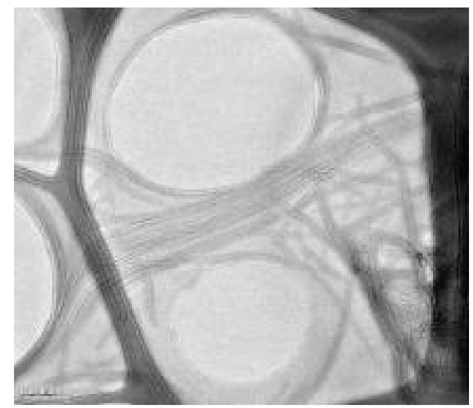




Polymeric Thin Film



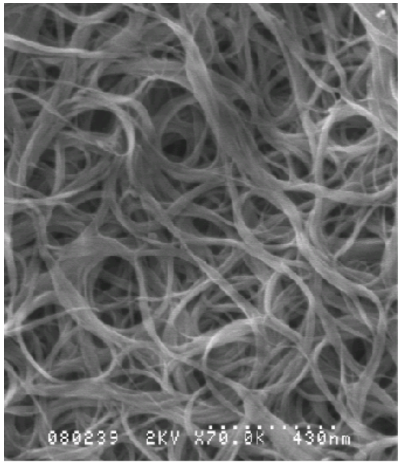
TEM - Quantum Dot Doped Polymer

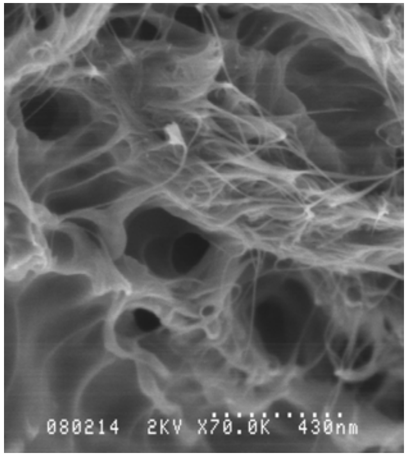


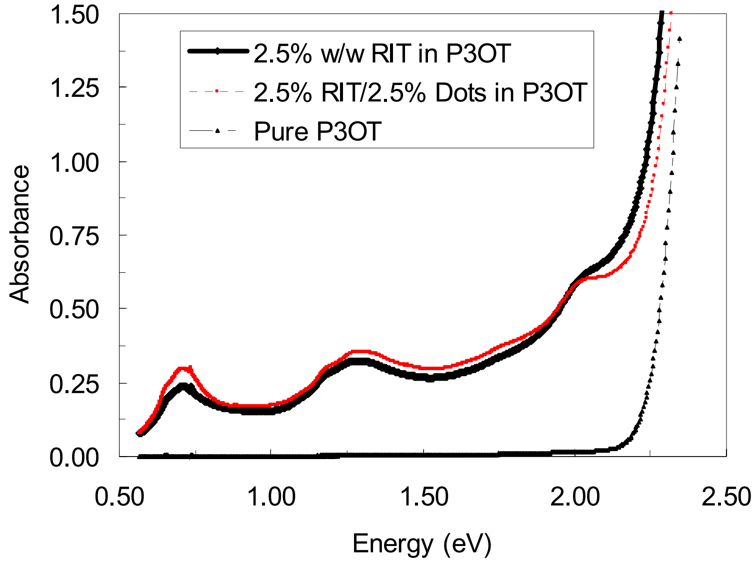
TEM - Carbon Nanotube Doped Polymer

Preliminary Results

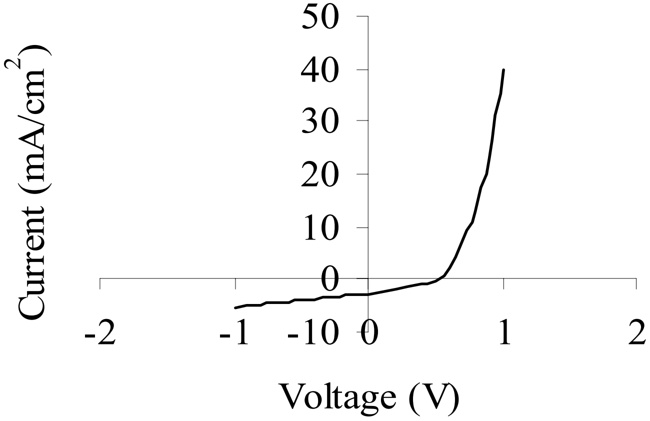
Doped P3OT Thin Films

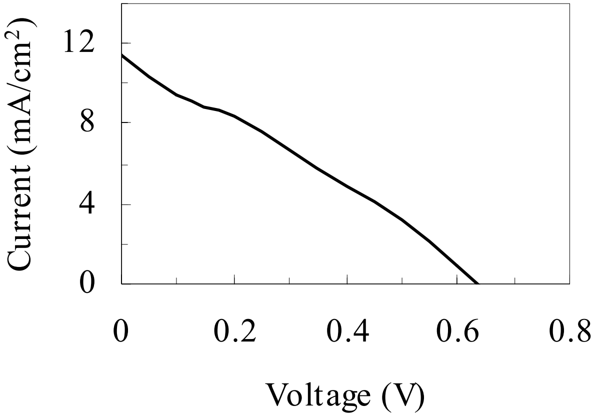






Nanotube/P3OT Solar Cell





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Technical Objectives

The overriding technical objective with regard to this work is to produce, model, and characterize thin film polymeric solar cells that utilize high purity single wall carbon nanotubes, semiconducting quantum dots, and a combination thereof. The evaluation of these cells will be performed in the context of their potential application to SSP. The technical objectives of the combined three-year effort can be summarized as follows:

1. Synthesis and characterization of nanostructured materials.
2. Composite material and device modeling.
3. Photophysical study of doped conjugated polymer composites.
4. Fabrication of thin film photovoltaic devices.
5. Optoelectronic characterization of prototype devices.
6. Data analysis.
7. Optimization of devices.
8. Space environmental testing of devices.
9. Dissemination of results and recommendations for future study.

Historical Evolution

M. Wolf, *Proc. of IRE* **48**, 1246 (1960).

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K. Barnham and G. Duggan, *J. Appl. Phys.* **67**, 3490 (1990).

J. Li, et. Al., *Appl. Phys. Lett.* **60**, 2240 (1992).

M. Keevers and M. Green, *J. Appl Phys.* **75**, 4022 (1994).

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A. Luque and A. Marti, *Phys. Rev Lett.* **78**, 5014 (1997)

W. Huynh, et. al., Adv. Mat. **11**, 923 (1999).

K. Barnham, et. al., *Appl. Phys. Lett.* **76**, 1197 (2000)

Proposes the Impurity Photovoltaic Effect (IPV)

Argues against IPV and cite recombination losses make them impractical.

SQ model predicts single junction 30% max. η

Propose junction limits imposed on tandem cells can be eliminated using MQW's η > 40%

Claim 35% η impurity PV effect Si Cell. Retract after comments by Luque, Werner, etc.

Show IPV effect with deep Indium defects in Si can exceed SQ η

Inverse Auger mechanism with QE > 1 yields η limit of 43%

Show QD intermediate band can exceed SQ eff. and tandem cells η of 63%

Propose Quantum Dot Concentrator Cells

CdSe Solar Cells with Quantum Dots and Nanorods

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